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THE FUSION MATERIALS IRRADIATION TEST FACILITY*

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Introduction

In all of the fusion-reactor concepts being considered, magnetic confinement or inertial confinement, the wall adjacent to the plasma must maintain its integrity for several years under sustained 14-MeV neutron irradiation. Because no fusion reactor is available in which candidate first-wall materials can be evaluated, an alternative method of neutron generation must be used. The Department of Energy, Office of Fusion Energy, has chosen a method to achieve the desired neutron environment that uses a beam of 35-MeV deuterons impinging on a flowing lithium target. About five per cent of the neutrons in the deuterons are stripped off and continue on through the target with an energy of about 14 MeV. The objective is to make a neutron flux capable of irradiating materials to projected end-of-life levels in about three years.

The Fusion Materials Irradiation Test (FMIT) Facility, shown in Fig. 1, will consist of a 35-MeV, 100-mA linear accelerator, a lithium system, two lithium targets, two test cells and support areas, and an appropriate building complex. The facility will be located on the Department of Energy Hanford Reservation near Richland, Washington. The Hanford Engineering Development Laboratory (HEDL) is responsible for overall management and direction of the project, design and development of lithium, experimental, and control systems, and will operate the facility. The Los Alamos Scientific Laboratory

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(LASL) is responsible for development and design of the accelerator. The Ralph M. Parsons Company is the Architect-Engineer and the J. A. Jones Construction Services Company is the Construction Coordinator.

Test Cell and Target

Because the facility's function is to test materials, the system's description will begin at the experimental area. The experimental complex, shown in Fig. 1, contains the two test cells, neutron shielding, and service areas.

Figure 2 shows the interior of one of the 8-ft by 5-ft by 6-ft-high test cells with the target assembly, a test module, shielding plug, and two sliding shielding blocks that can be moved to permit access into the irradiation cell. Also available are TV monitors, a positioner, a remote manipulator system, and provisions for active and passive dosimetry. The test-cell complex will be cooled with a nitrogen gas cooling system.

The target, shown in Fig. 3, is designed to produce a stable curtain of liquid lithium 10 cm wide by 4 cm high by 2 cm thick. The deuteron beam is focused to a 1- by 3-cm spot in the target. As a result of the deuterium-lithium stripping reaction, average fluxes of 1.4×10^{15} n/cm²-s will be created in a 10-cm³ volume adjacent to the target back wall, and 2.2×10^{14} n/cm²-s, averaged over 0.5 liter, immediately behind the target. These flux levels afford damage rates in material specimens greater than that of a first wall of a 1 MW/m² fusion device in over 100 cm³ of volume. Accelerated testing by as much as a factor of 5 can be achieved in specimens near the target back wall. The target

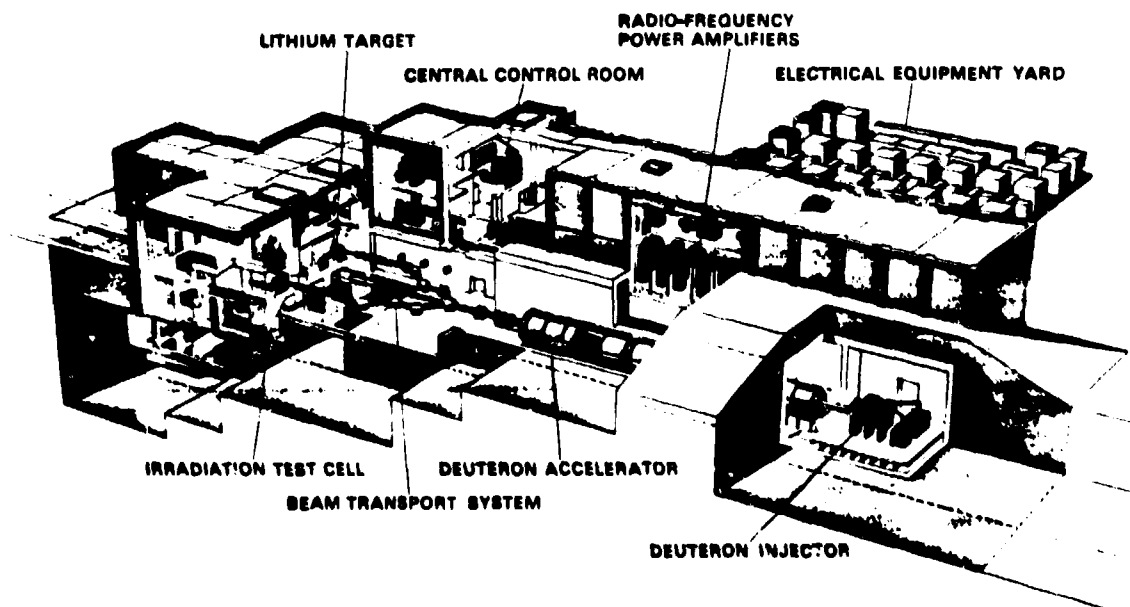


Fig. 1. The FMIT Facility.

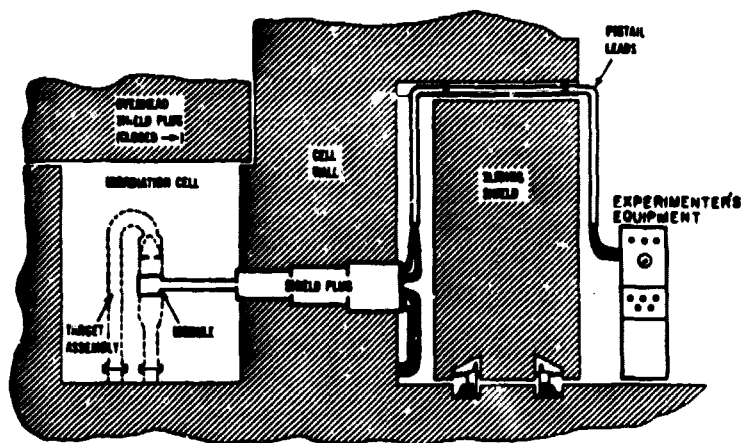


Fig. 2. The test-cell layout.

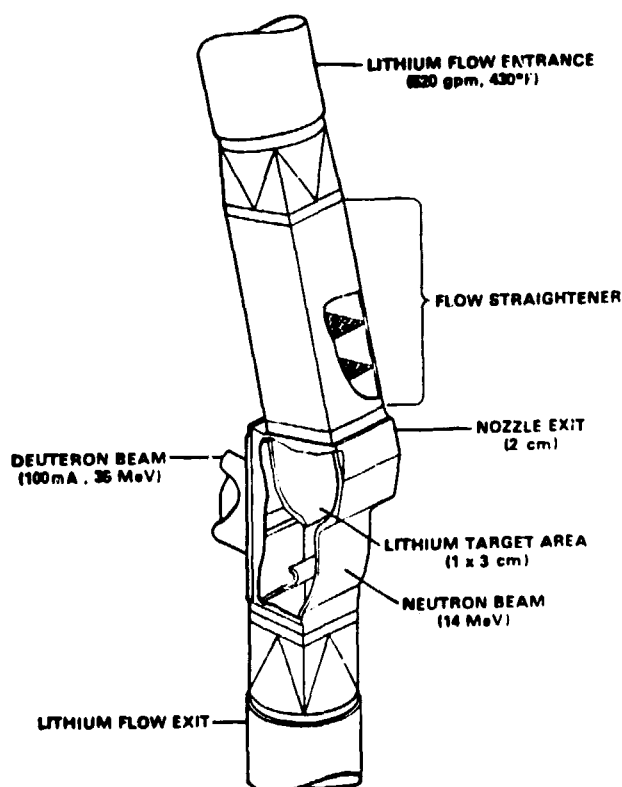


Fig. 3. Lithium target assembly.

design has been tested successfully with water models. A prototype lithium target is being fabricated for testing in a recently completed, experimental lithium system.

The horizontal test assembly (HTA), shown in Fig. 4, is the initial vehicle that will be used to irradiate a test-specimen module. The module will be positioned directly behind the lithium target. The HTA consists of a shield plug that penetrates the test-cell wall, providing shielded instrument penetrations, a test stalk that houses a NaK cooling system to reject a maximum of 2 kW of experiment and system heat, and the test-specimen module that is comprised of three test-specimen chambers. The

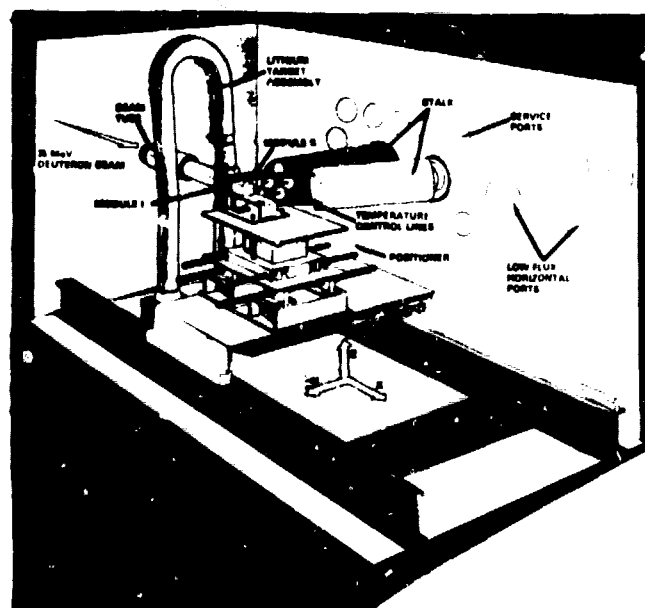


Fig. 4. Horizontal test assembly.

lithium system provides the flowing lithium curtain and removes the 3.5-MW of heat that is continuously generated by the deuteron beam stopping in the target. The lithium design flow rate is 510 gpm. Lithium enters the target at 220°C and leaves at 275°C. A full-scale, experimental lithium system has been fabricated and is in the initial stages of operation at Hanford.

The Accelerator

The accelerator's function is to produce a deuteron beam and transport it to the lithium target. The accelerator,² like the rest of the system, is being designed to operate with high reliability and high availability because the facility is essentially a neutron factory that must irradiate samples continuously for several years.

Table I gives the accelerator's specifications. The unique feature of this accelerator is its 100% duty factor. A pulse of deuterons is produced in every cycle, generating a 3.5-MW beam. Over 5 MW of rf power is required for this accelerator.

TABLE I

FMIT ACCELERATOR SPECIFICATIONS

Particle	deuterons
Duty factor	100%
Frequency	80 MHz
Output energies	20 MeV and 35 MeV
Maximum beam current	100 mA
Average energy gain	1 MeV/m
Injector energy	100 keV
Low-beta accelerator (RFQ) output	2 MeV
Number of linac tanks	2
Number of drift tubes	72
I.D. linac tanks	2.48 and 2.40 m
Length—linac tanks	32 m
Total length—accelerator	47.7 m
Total rf power	5.35 MW
Operating pressure	10^{-6} torr

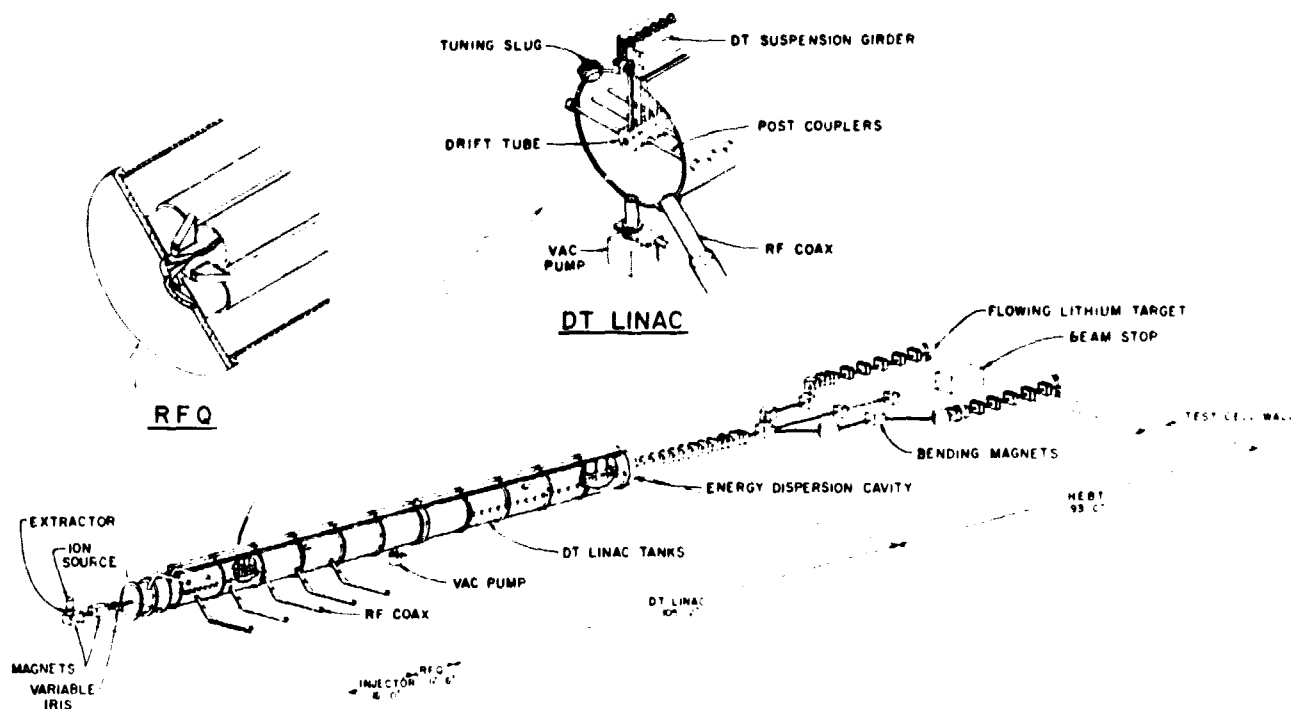


Fig. 5. Accelerator layout.

Figure 5 shows the layout of the entire accelerator. The system includes: the injector that produces a continuous beam of 100-keV deuterons; the radio-frequency quadrupole (RFQ) that captures the beam, bunches it, and accelerates it to 2 MeV; the drift-tube linac that accelerates the beam to 35 MeV; the energy dispersion cavity (EDC) that spreads the energy from the linac; and finally the high-energy beam transport system that transports and focuses the beam onto either target. The essentials of each of these subsystems will be described.

The Injector

The injector³ generates a steady beam of ions, accelerates the beam to 100 keV, and transports it to the RFQ structure. The injector, shown in Fig. 6, now uses a cusp-field ion source based on a Culham design.⁴ The source uses a water-cooled, cylindrical anode with 30 ceramic bar magnets arranged axially around the anode wall to generate a periodic cusp magnetic field inside the anode. This field prevents the electrons in the plasma from going directly to the anode and increases their lifetime in the chamber, which significantly increases the efficiency of the source. A single-gap, 100-kV extractor accelerates the beam. The gas efficiency of this injector is over 40% and the filament life is expected to exceed 350 h. A prototype model of the injector has produced a 200-mA hydrogen beam and also has operated satisfactorily with deuterium.

The Radio-Frequency Quadrupole

The RFQ serves two functions; it converts the injector 100-keV dc beam into pulses suitable for an Alvarez-type linac and it accelerates the beam to 2 MeV, which is an appropriate energy for the first drift tube in the linac. The principle of the RFQ was first developed by the Russians.⁵ The system,⁶

shown in Fig. 7, focuses with electrostatic quadrupole fields that are uniform along the beam channel. Off-axis particles in such a structure are focused in one plane and defocused in the other, and vice versa, on alternate rf cycles. This results in a strong focusing system that transports a beam along the axis without acceleration. Longitudinal acceleration is due to mechanical perturbations on the vanes. If the

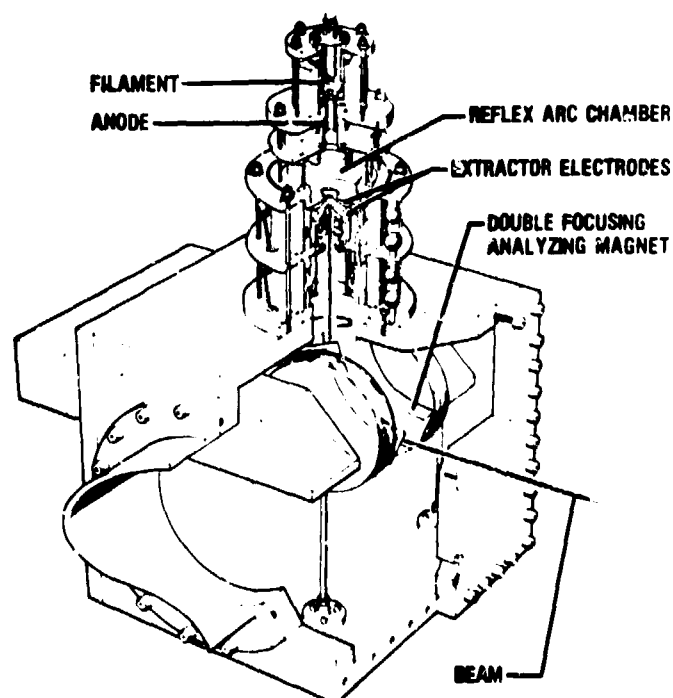


Fig. 6. Injector.

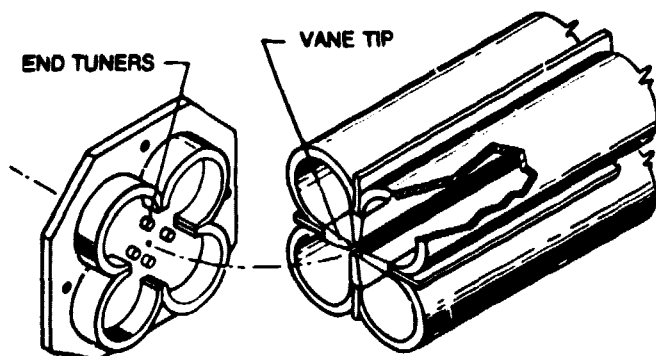


Fig. 7. The RFQ assembly.

distance between electrodes of similar polarity varies periodically along the beam channel, a longitudinal field results that will bunch and accelerate the incoming beam.

The LASL is engaged in a vigorous program to develop the RFQ as the low-beta accelerator for the FMIT. Cold models have shown that stable rf modes exist in the structure, and accelerating fields exist on axis with controllable profiles. Mechanical design and fabrication methods also have been developed for this complex structure. A particle-beam proof-of-principal test, operating at 440 MHz, will begin by 1980. A full-scale, 80-MHz prototype system is scheduled for testing in 1981.

The Drift-Tube Linac

The drift-tube linac,⁷ shown in Fig. 8, accepts the 2-MeV beam pulses from the RFQ and accelerates

them to either 20 MeV or 35 MeV. The linac has two tanks with an intertank spacer between them. The first tank produces a 20-MeV beam that can be transported through the unenergized second tank to the target. The FMIT is expected to operate at this energy only about 1% of the time. The energized second tank accelerates the beam to 35 MeV. Two slug tuners in each tank maintain resonance, and post couplers in the tanks stabilize the rf field.

The drift tubes, which are about 40 cm in diameter, will be supported on a single stem that also will carry the cooling water in and out of the drift tubes. The drift tubes will be made of stainless steel castings that are copper plated. The quadrupole magnet in each drift tube will be wound with a water-cooled copper conductor. The pole pieces and yoke will be made from ordinary magnet iron.

A group of drift tubes will be suspended in the tank from a 10-ft-long girder. This will allow all drift tubes on a girder to be aligned before they are installed in the tank. Final alignment will be done by aligning the eleven girders in the two tanks. With this girder system, no one has to enter the tank for drift-tube installation and maintenance. This would be impossible after operation has begun because of the radiation hazard.

The Energy Dispersion Cavity

The EDC consists of a two-cell, rf cavity that adds to and subtracts from the beam 750 keV so the net energy is not changed. The EDC operates at an unsynchronized frequency of about 85 MHz so the normally Gaussian energy distribution of the linac is converted to more of a rectangular distribution. This energy spread is necessary to distribute the energy through the 2-cm thickness of the lithium target to avoid boiling in the target.

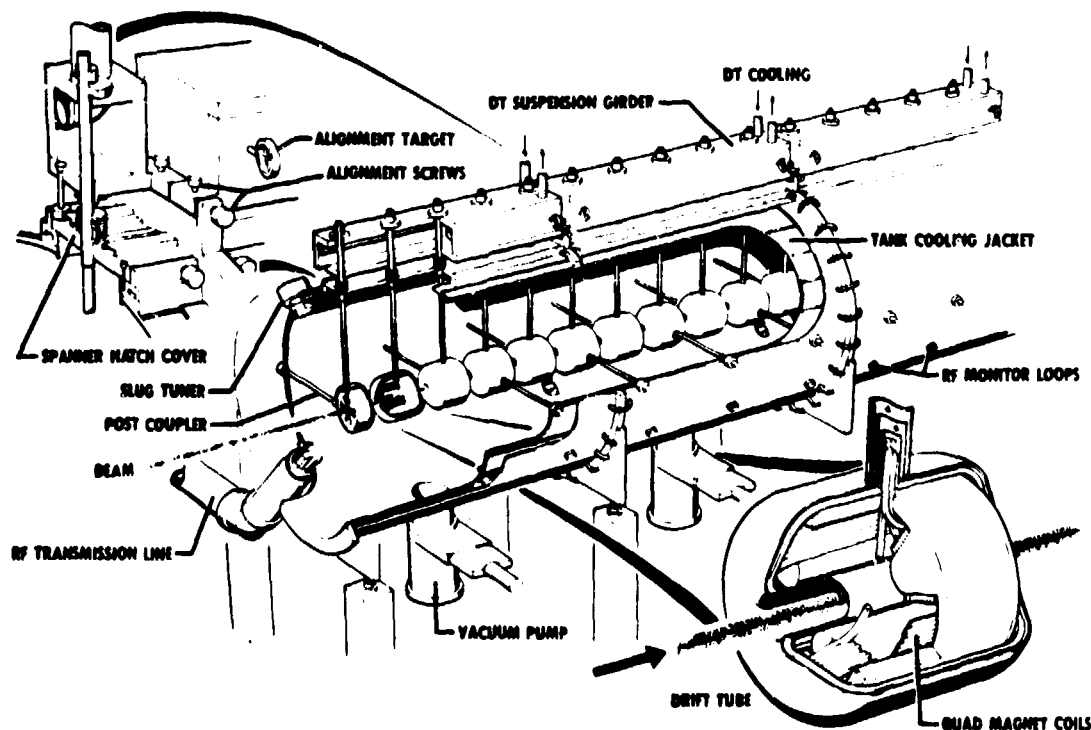


Fig. 8. The drift-tube linac.

The High-Energy Beam Transport (HEBT)

The HEBT,⁸ shown in the layout in Fig. 5, is designed to transport the 20-MeV or 35-MeV beam to either of the two target cells and focus the beam to a 1- by 3-cm spot on the lithium target. It also will transport the beam to the beam stop during accelerator tune-up. The first section of the HEBT extends the periodic quadrupole system of the linac and is used for beam diagnostics. The remainder of that section matches the beam into the first bending magnet. The lateral displacement to the two cells is accomplished by a periodic bending system of three other bending magnets that are identical but reversed for the opposite arm. The final magnet in each arm focuses the beam to a spot on the target.

The Radio-Frequency System

The 80-MHz FMIT rf system⁹ must supply the required 5.35 MW of continuous rf power to the accelerator and maintain the proper phase and amplitude required for stable operation. Because the rf system will be one of the least reliable parts in the accelerator, some redundancy is necessary. The first linac tank will be driven by seven rf modules and the second tank will be driven by six modules. If one module in either tank fails, it can be isolated quickly and the remaining modules can operate the accelerator at full power, while staying within the power rating of the module.

A module consists of a low-power (100-W) stage that is being designed by LASL, and a high-power (600-kW) stage that is being designed and built by industry. The final output tube is an EIMAC 8973 tetrode. This tube has operated satisfactorily for several hours at over 500 kW at 80 MHz. Screen grid heating indicates that the tube can produce 600 kW. In the system, each module normally will operate at slightly over 400 kW. Two modules will drive the RFQ so the entire rf system will contain 15 modules.

The Prototype

A 5-MeV, 100-mA, cw accelerator prototype system will be built at LASL. It will contain a prototypical injector system, an RFQ, a linac containing the entire first girder of FMIT, and four rf modules, as well as a control system, vacuum system, and much of the diagnostics that must be developed for this high-powered cw accelerator. A new building has been constructed to house the prototype. The prototype injector will begin operating in early 1980; the RFQ will be added in 1981, and the entire 5-MeV system will be operational in 1982.

Summary

A Fusion Materials Irradiation Test Facility is being designed to be constructed at Hanford, Washington. The system is designed to produce about 10^{15} n/cm-s in a volume of ~10 cc and 10^{14} n/cm-s in a volume of 500 cc. The lithium and target systems are being developed and designed by HEDL while the 35-MeV, 100-mA cw accelerator is being designed by LASL. The accelerator components will be fabricated by U. S. industry.

The total estimated cost of the FMIT is \$105 million. The facility is scheduled to begin operation in September 1984.

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